INVESTIGATIONS OF uv TEA N_2 LASERS

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A simple transversely excited atmospheric (TEA) nitrogen uv laser with „double" Blumlein-circuit switched by triggered spark gap was investigated. The Blumlein-circuits were based on flat-plate wave guide and ceramic capacitors, as well. The output laser energy and the pulse shape exhibited strong dependence on the setting of the angle between the two laser electrodes, but less on the electrode separation. The minimum flowing rate to obtain the maximum output energy was determined at 25 and 50 Hz repetition rate.

Introduction

There is a rapidly increasing interest in transversely excited atmospheric (TEA) nitrogen lasers [1—7]. The first TEA N_2 lasers were designed utilizing the standard N_2 laser constructions. This approach has inevitably led to a lot of problems which are crucial to the stable operation of TEA N_2 lasers and, thus, need thorough investigations. In this paper we describe the most important components used and give an account of our experimental results.

Transmission lines of the TEA N_2 laser

In the case of low-pressure N_2 lasers population inversion can be achieved by a current density of several ten kA/cm^2, providing that the initial rate of current rise is as high as 10^{13} A/sec and the length of the excitation current pulse is not longer than the radiative lifetime of the laser transition. The initial rate of current rise, *i.e.* the building up of the discharge in the laser channel must be still faster with TEA N_2 devices due to the higher gas pressure, since there is an intensive collision quenching of the excited molecules. In the case of the Blumlein-circuit such very short pulsed discharges can be realized either with a low characteristic impedance flat-plate wave guide or with the application of ceramic capacitors of low self-inductance. The first type of the Blumlein-circuit is generally preferred [1, 2, 4]. The wave impedance may be reduced by parallel connection of two Blumlein-circuits. However, this "double" Blumlein-type transmission line was applied with low-pressure nitrogen lasers [9, 10], and there is only one report on the TEA N_2 laser of double parallel-flat design [6].

Our choice on the double Blumlein-circuit seemed to be advantageous for TEA N_2 lasers since

(1) with the parallel connection the wave impedance is half of that of the single line, and the capacity (thus, the input electric power) is twice as high as with the single Blumlein-circuit. Note that due to the breakdown voltage of the wave guide and of the capacitors this is the only means to increase the input electric power.
(2) The plasma becomes curved due to the strong accompanying magnetic field of the single Blumlein-circuit. This phenomenon is considerable and disturbing, if the electrodes have edge profils, but it can be eliminated with the double parallel flat-plate design.
(3) The double Blumlein transmission line can be built in a compact folded form [10]. The outer side is at ground potential and so the driving electric circuit is shielded having low radio-frequency interference, a feature which is highly recommended for the operator's safety.

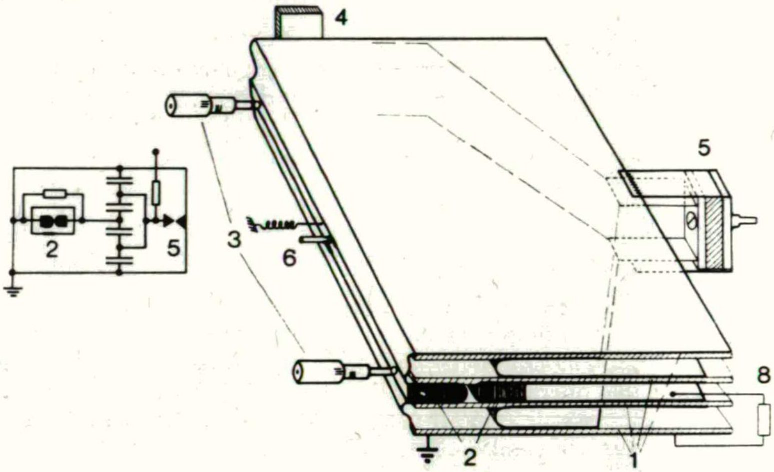

Fig. 1. Exploded view and circuit diagram of TEA N_2 laser with „double" flat-plate Blumlein-circuit. 1 — printed circuit boards, 2— laser electrodes, 3 — micrometers, 4 — flat mirror, 5 — triggered spark gap, 6 — gas inlet, 8 — resistor.

On the basis of the above-mentioned general considerations we designed two different arrangements for TEA N_2 transmission lines laser. One of the transmission lines was a double flat-plat-type (Fig. 1). Its wave guide was etched from a 1,5 mm thick double-sided copper-clad printed circuit board. The dielectric insulation was fiberglass-epoxy composition having dielectric constant $\varepsilon=6{,}24$. The active surfaces of the printed circuit boards were 300×200 mm, and the edges of the boards were etched in 30 mm width to improve high voltage insulation. The transmission lines were connected to the movable (outside) electrode with a flexible copper foil. The characteristic impedance of the circuit was $Z_0=0{,}34$ ohm.

The other Blumlein-circuit was based on twenty barium titanate capacitors arranged in four lines as seen in Fig. 2 (KVI—12, 1 nF, TV 12 kV, 32 mm diam$\times$ $\times$12 mm). One of the output terminal of the capacitor bank was soldered to the copper plate of the transmission line and the other one to the copper electrode. Such low inductance capacitors are very advantageous if a compact laser head of small size is needed.

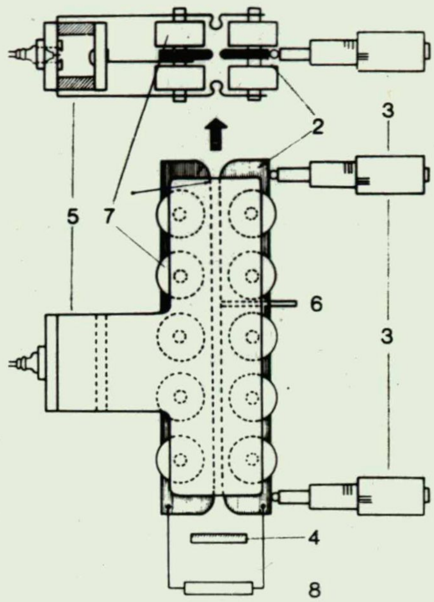

Fig. 2. Top and cross-sections view of TEA N_2 laser with barium titanate capacitors „double" Blumein-circuit. 2 — laser electrodes, 3 — micrometers, 4 — flat mirror, 5 — triggered spark gap, 6 — gas inlet, 7 — capacitors, 8 — resistor.

Triggered spark gaps

A uniform switching of the transmission line is very important to a stable lasing action. Either a thyratron or a simple spark gap can be used for discharging the Blumlein-circuit. The main advantages of applying a thyratron are the speed, the short jitter (few nsec), the noiseless operation, and the well reproducible pulse shape and energy. Still, triggered spark gaps are widely used, especially in laboratory conditions.

The Blumlein-circuits of our TEA N_2 lasers were switched by triggered spark gaps (Fig. 1—2). Two methods were applied for triggering the discharge of the spark gaps (Fig. 3). In the first set up (Fig. 3a) the ignition electrode is between the two main electrodes. This is a simple construction but its electric circuit is complicated. In the second set up (shown in Fig. 3b) the ignition electrode is in the middle of one of the main electrodes. The construction of this spark gap is more complicated but its triggering circuit is simpler.

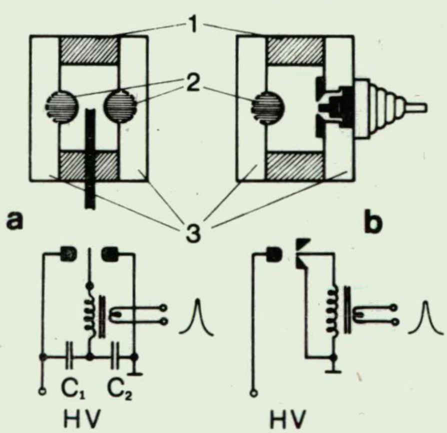

Fig. 3. Triggered spark gaps and their schematic circuit diagrams. Ignition electrode is between the two main electrodes (a), and in the middle of one of the main electrode (b). 1 — ceramic insulations, 2 — steel balls, 3 — aluminium walls.

We investigated the delay between the switching of the spark gap and the laser action. This time depended strongly on the voltage, the separation between the two laser electrodes and the pressure. A typical delay is about 30 nsec with the TEA laser using parallel-flat circuit (the charging voltage is 12 kV, the pressure is 10^{-1} MPa and the laser electrode separation 2.5 mm).

The triggering electric circuit was built from both separated elements and digital ICs. The spark gap always obtained the switching signal in the moment when the mains voltage is zero. Thus, the radio-frequency interference could be decreased and the high-voltage supply unit could be effectively protected.

Laser channel

The laser pulse duration can be decreased below 1 nsec increasing the gas pressure in the laser channel [3, 8]. A certain length of the laser channel is needed for high-power output, so that the pulse duration will become shorter than the transit time through the laser channel. Therefore, travelling wave excitation technique should be used. The travelling wave excitation is accomplished by running a high-voltage step along the electrodes with about light velocity and, therefore, the potential distribution along the electrodes is uniform in a few nsec (1—2 nsec), but the current and the laser pulses follow the voltage pulse only 10—30 nsec later. For this reason the evolution of the travelling-wave type pulsing excitation seems to mainly depend on the geometry of the gas discharging region (electrode profil, separation, angle and gas pressure), rather than on the time deviation with the voltage step [3, 5].

During the preliminary experiments we obtained a typical total laser pulse duration of 1.5—2 nsec with TEA N_2 devices varying the length of the laser channel. This suggested that for optimal travelling wave excitation a length of 45—60 cm or longer is suitable. However, on the other hand it proved to be highly important how the electrodes surfaces were processed. Due to technical reasons we decided to apply a laser channel of 300 mm (or shorter) with front-aluminized flat mirror.

The laser electrodes were made of 6 mm thick copper plates. The active electrode surfaces were cylindrical, because of the higher stability and the better arc shape as compared to those results experienced with edge electrodes. The tips of the electrodes were Rogowski-profile; that way we tried to approximate the homogeneous electric field at the end of the electrodes. The separation and the angle between the two electrodes were controlled by two micrometer heads fitted near the ends of the electrodes. The accuracy of setting the spacing between the electrodes at the rear and the front of the laser channel was 0.01 mm. The nitrogen gas inlet was about the midpoint of the outer electrode with both TEA laser arrangements. The gas flow was directed along the active laser channel forward and towards the mirror with an outlet at the ends of the laser channel (Fig. 1—2).

Experimental

The output energy of the TEA N_2 lasers was recorded with a nickel-oxide calorimeter (Laser Instrumentation, type 07.14 NO) and a Kipp & Zonen compensograph (type BD6). The pulse energy was calculated from average power reading and average repatition rate measurements. An oscilloscope (S7—10 type) and ITL vacuum coaxial photodiode-type (HSD 1850) were used to determine the peak output power and the pulse width. The overall resolurion time was 0.4 nsec.

Results and discussions

Our investigations show that the laser energy/pulse (E), the observed light pulse shape as well as the vertical and horizontal divergence of the TEA N_2 laser depend on the spacing (d) and the angle (φ) between the two laser electrodes. We measured the laser energy with both types of TEA N_2 laser and a typical set of data is shown in Fig. 4 (at 11 kV, 10 Hz and 0,25 m³/h) when the length of the laser channel with flat-plate Blumlein-circuit was 300 mm. The rear (d_r) electrode spacing was

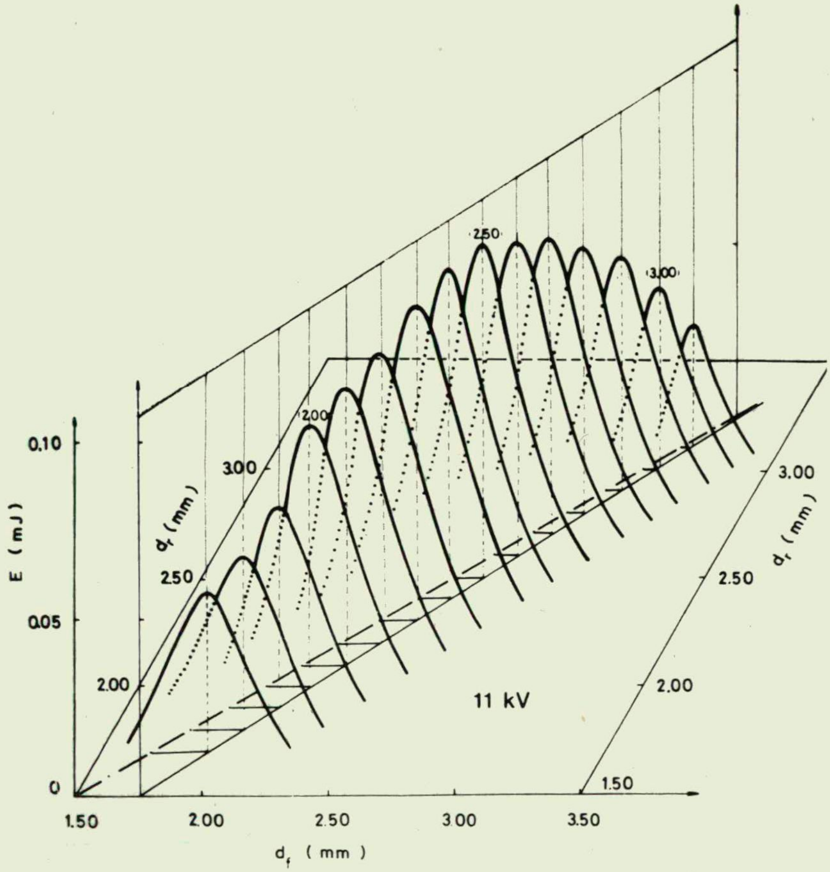

Fig. 4. Dependence of the output energy/pulse (E) on the front (d_f) and the rear (d_r) electrode separation. The dashed dotted line refers to the parallel electrode positions (.—.), while the full line refers to the optimum electrode positions. Charging voltage −11 kV, repetition rate 10 Hz, flow velocity 0,25 m³/h, with flat-plate Blumlein.

changed from 1.7 mm through 3.1 mm while the front electrode spacing (d_f) was varied between $d_r-0.40$ mm and $d_r+0.40$ mm. The output energy showed a maximum when the electrode spacing was slightly closer at the mirror (rear) end, but this difference in spacing of the ends of the electrodes depended on the absolute electrode

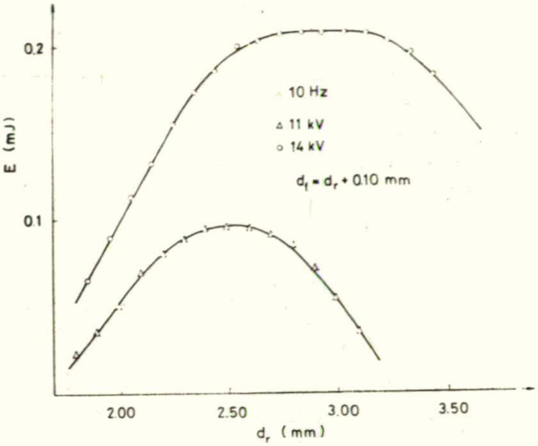

Fig. 5. Output energy/pulse versus rear (d_r) electrode separation ($d_f = d_r + 0.10$ mm). Charging voltages $\Delta - 11$ kV, ○ $- 14$ kV, repetition rate 10 Hz, optimum gas flow.

separation. In one case (shown in Fig. 4) the difference was 0.22 mm with $d_r = 1.70$ mm and 0.05 mm with $d_r = 3.00$ mm. (Even in terms of the angle between the two laser electrodes there was a change from 0.60 to 0.15 mrad for the optimal setting of those cases.)

In Fig. 5 the section of the former series of measurements is shown when $d_f = d_r + 0.10$ mm with 11 kV and 14 kV. The optimal electrode spacing was different with changing charging voltage.

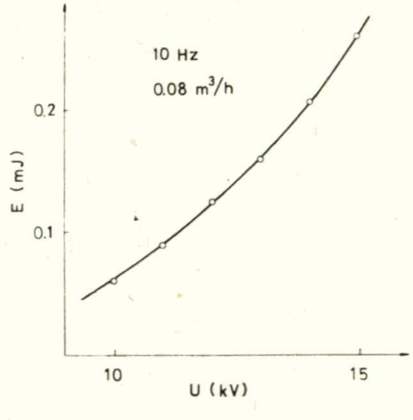

Fig. 6. Output energy/pulse (E) plotted against charging voltage (U). Repetition rate 10 Hz, flow velocity 0.08 m³/h.

Taking the output laser energy/pulse which depends on the spacing and the angle between electrodes into account, we investigated the effect of the charging voltage (U) on the energy (Fig. 6).

The most important result was that both the energy/pulse and the pulse shape (and also the divergence) strongly depended on the angle between two laser electrodes (Fig. 7). (Zero mrad corresponds to the parallel position of electrodes, negative and positive values correspond to departure at the mirror (rear) and the output (front) end, respectivelly.) Studying the TEA N_2 laser pulse shapes (insert in Fig. 7) (with a φ of -0.66 to $+1.33$ mrad) we found that the intensity of the amplified spontaneous emission (ASE) travelling toward the output end was increased whereas the ASE travelling toward the mirror end was decreased, *i, e.* the forward-to-back ward ratio of the emission was increasing and the shape of total emission became gaussian. The half-width of the gaussian pulse shapes were 1 nsec.

The results that the energy/pulse curve has maximum at +0.33 mrad (and not at the parallel electrode position and so with unsymmetrical output) can be explained by the fact that the ASE travelling at first toward the mirror runs through the laser channel twice.

Both the horizontal (x) and vertical (+) divergence depend on φ and this dependce is determined only by the geometrical parameters of the laser channel without resonator.

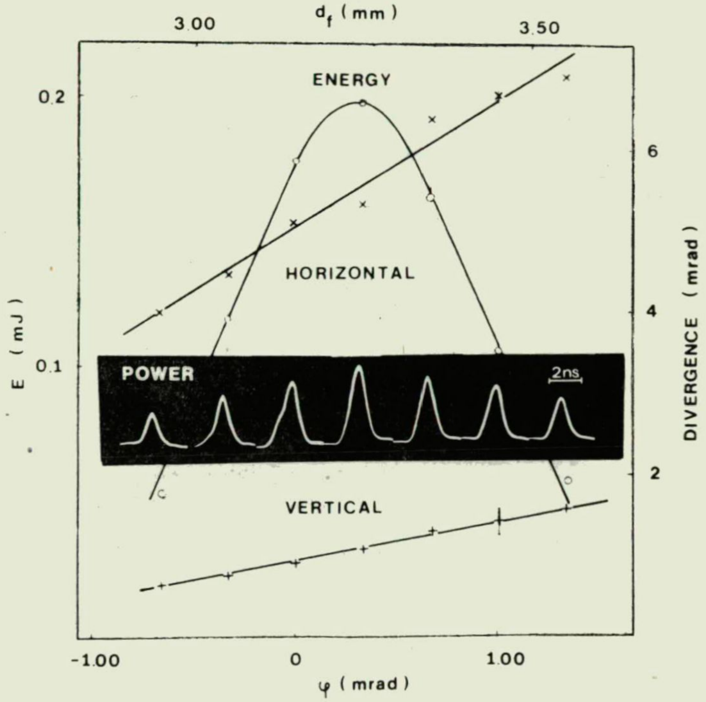

Fig. 7. Dependence of the output energy/pulse (E) (o), the horizontal (x) and the vertical (+) divergence and the laser pulse shapes on the front electrode separation (d_f) and/or angle between the two electrodes (φ), respectively with d_r=3.1 mm. Charging voltage 14 kV, repetition rate 10 Hz.

We can summarize the results according to optimal setting of the laser electrodes as follows: The unevenness of the cylindrical electrode surfaces (so of the geometrical direct line) mustn't be larger than 10 microns, and the accuracy of the angle setting between the two electrodes should only be several 10^{-1} mrad.

During the further experiments we found that the optimal setting of the laser electrodes was not enough to achieve stable and uniform discharge. We investigated the influence of the flow velocity (dV/dt: the derivative of gas volume (V) over time (t)) of nitrogen (technical grade, purity 98%) on the average power with various repetition rate (d_r=2.6 mm, d_f=2.7 mm) (Fig. 8). The average power firstly increased parallel with increasing dV/dt and then for high flow rates the output energy was saturated. This means that a certain quantity of nitrogen is necessary to the optimum output energy. These values were 0.5 and 0.9 m^3/h with 25 and 50 Hz, respectivelly, and these correspond well to the calculatted values assuming that the total volume of the laser channel should be exchanged after each discharge. A slight deviation was observed at 10 Hz, since less nitrogen was needed at this repetition rate than expected assuming total exchange.

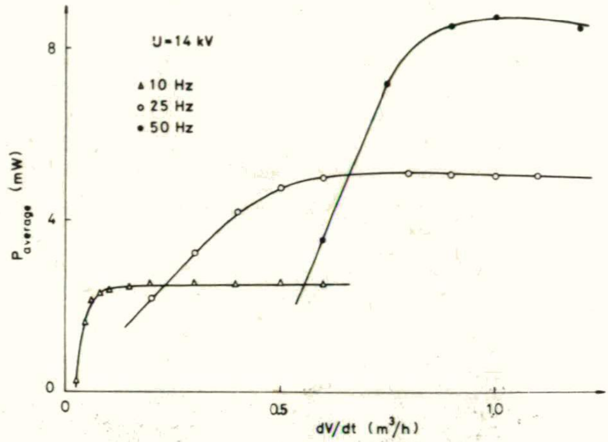

Fig. 8. Influence of flow velocity (dV/dt) on the average power at various repetition rates. Charging voltage 14 kV, $d_f = 2.90$ mm, $d_r = 2.80$ mm.

Finally we can conclude that the optimal setting of the cylindrical electrodes and a poper gas flow together are necessary to the stable and uniform discharge (without special stabilization technique [8]), and to the maximum output energy.

We have repeated all these investigations with a shorter (200 mm) TEA N_2 laser with ceramic capacitor's Blumlein-circuit, and the results were essentialy the same. We also varied the distance between the mirror and the rear end of the electrodes and obtained more complicated pulse shapes. These results will be published in a forthcoming paper.

Thus, the TEA N_2 laser is a simple and suitable device for pumping dye lasers, to investigate photochemical reactions and radiative life time of several compounds.

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ИССЛЕДОВАНИЯ N_2 ЛАЗЕРОВ ВОЗБУЖДЁННЫХ ПОПЕРЕЧНЫМ РАЗРЯДОМ ПРИ ДАВЛЕНИИ 760 ТОРР

И. Шанта, Б. Рац, Л. Козма и Б. Немет

Исследовались простые ултрафиолетовые азотные лазеры возбуждённые поперечным разрядом при давлении 760 торр (TEA N_2). Лазеры работали «двойным» контуром Блумлеина, с управляемым разрядниковым включателем. Контур Блумлеина был построен из плоского волновода а также из керамических конденсаторов. Энергия в импульсе лазера и форма импульса сильно зависят от настройки угла между лазерными электродами, а в меньшей мере меняются от расстояния электродов. Установлено, что необходимо определённое количество азота чтобы получить максимальную энергию, при частоте повторения импульсов 25 и 50 гц.